Intercomparisons of the Harvard Lyman alpha hygrometer and ICOS isotopic water instrument with the CFH and MLS instruments: Implications of recent results

Elliot M. Weinstock, J. B. Smith, R. Lockwood, D. S. Sayres, T. F. Hanisco, E. J. Moyer, J. M. St. Clair, and J. G. Anderson, Department of Chemistry and Chemical Biology, Harvard University, Cambridge MA 02138

W. G. Read, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

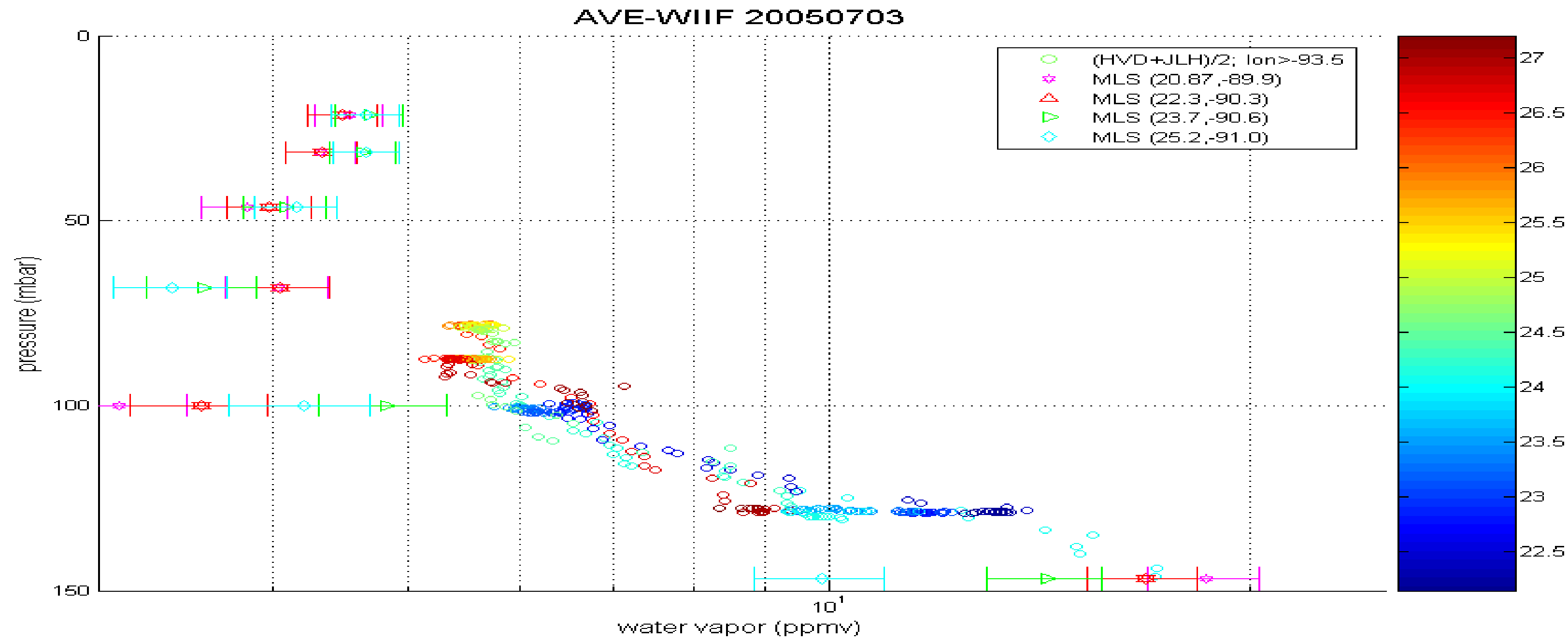
With acknowledgements and thanks to Holger Voemel, Bob Herman, Chris Webster for the use of their data.

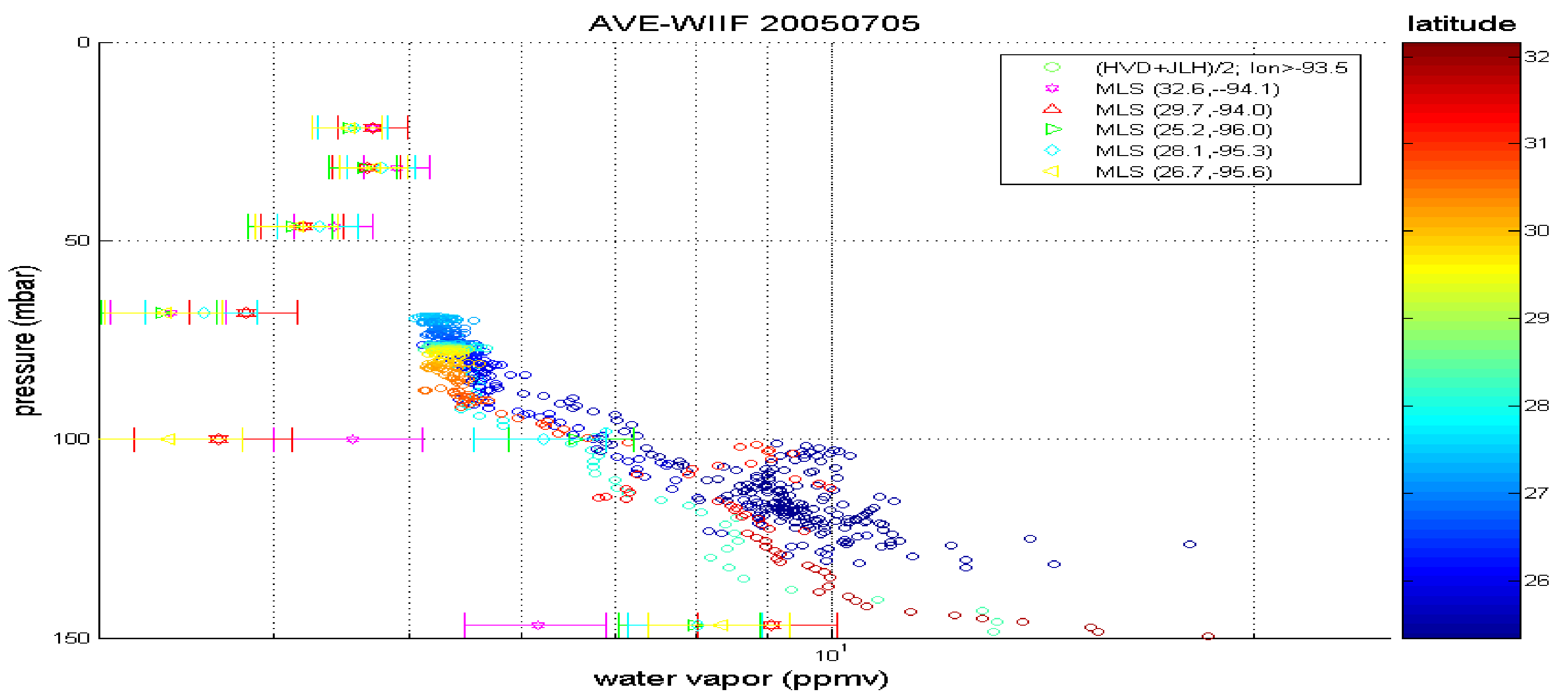
Questions to be explored

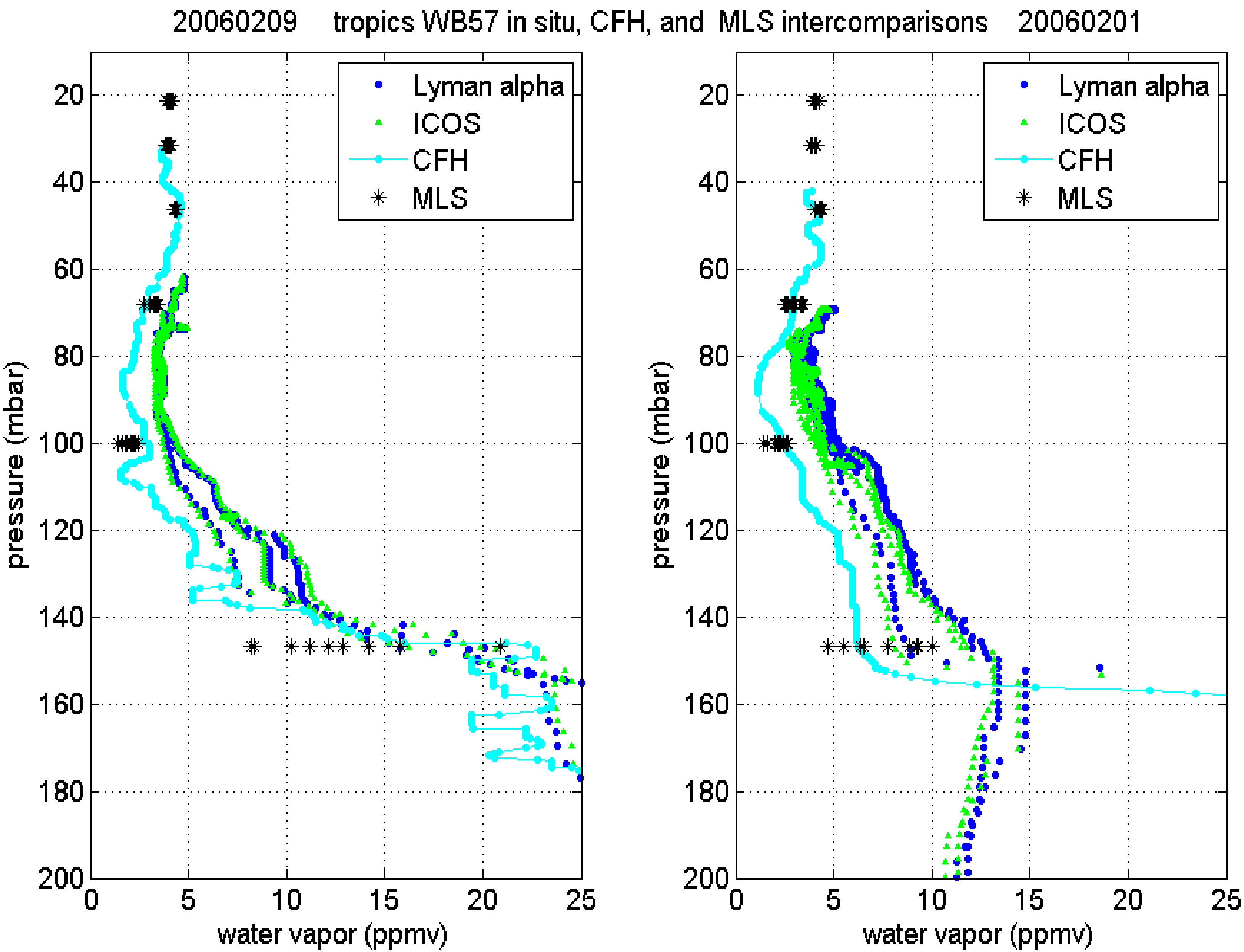
•Are intercomparison data from CRAVE and AVE-WIIF consistent?

•What have we learned from CRAVE regarding the accuracy of in situ water instruments needed for Aura satellite validation, especially regarding the previously observed systematic differences between the frost point hygrometer and in situ aircraft instruments?

•How do MLS version 1.5 and version 2 compare with in situ water vapor measurements?

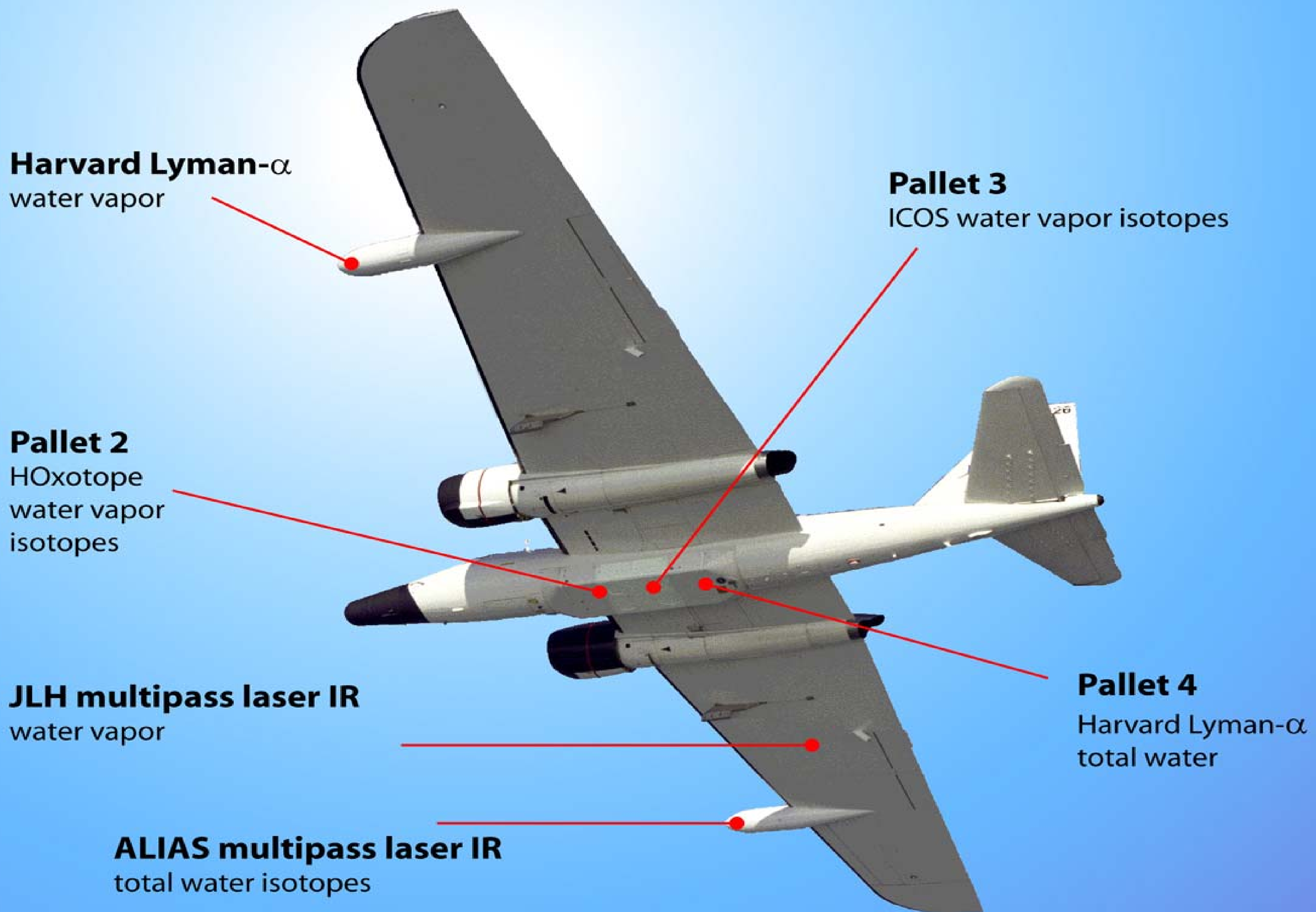

AVE-WIIF 20050703
(HVD+JLH)/2; lon>-93.5
MLS (20.87,-89.9)
MLS (22.3,-90.3)
MLS (23.7,-90.6)
MLS (25.2,-91.0)
pressure (mbar)
water vapor (ppmv)
0
50
100
150
10^1
27
26.5
26
25.5
25
24.5
24
23.5
23
22.5


AVE-WIIF 20050705
latitude
(HVD+JLH)/2; lon>-93.5
MLS (32.6,--94.1)
MLS (29.7,-94.0)
MLS (25.2,-96.0)
MLS (28.1,-95.3)
MLS (26.7,-95.6)
pressure (mbar)
water vapor (ppmv)
0
50
100
150
10^1
32
31
30
29
28
27
26



20060209 tropics WB57 in situ, CFH, and MLS intercomparisons 20060201
Lyman alpha
ICOS
CFH
MLS
pressure (mbar)
water vapor (ppmv)
20
40
60
80
100
120
140
160
180
200
0
5
10
15
20
25

Water measurements during AVE-WIIF



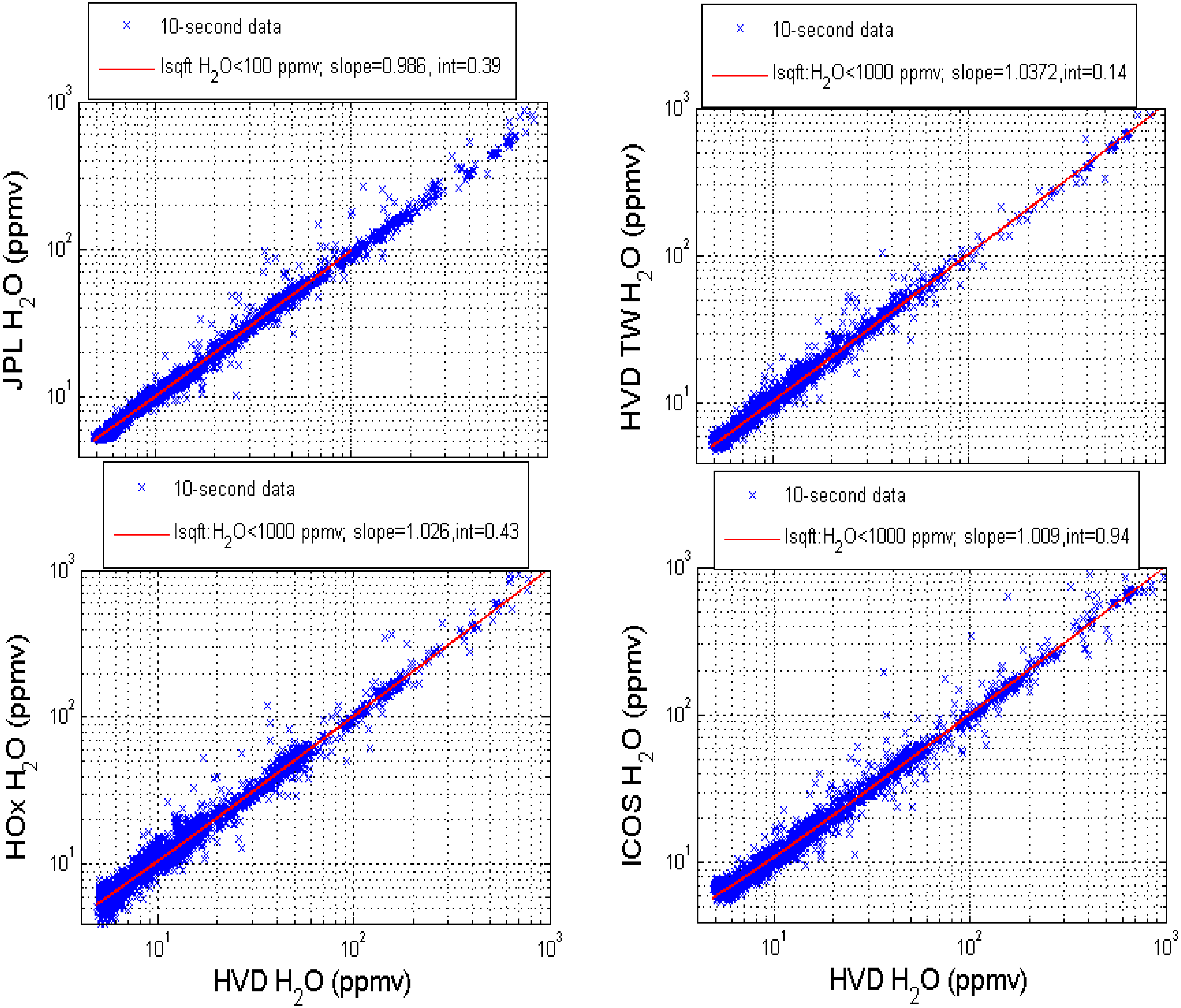
Instruments

AVE-WIIF

- Lyman α water vapor
- Lyman α total water
- JPL tunable diode laser hygrometer (JLH)
- Water vapor isotopes photodissociation laser-induced fluorescence (Hoxotope)
- Water vapor isotopes integrated cavity output spectrometer (ICOS)
- ALIAS water isotopes

CRAVE

- Lyman α water vapor
- JPL tunable diode laser hygrometer (JLH)
- Water vapor isotopes integrated cavity output spectrometer (ICOS)
- ALIAS water isotopes
- NOAA frostpoint (WB-57)
- Cryogenic frostpoint hygrometer (CFH)
- Balloon laser hygrometer


10-second data
lsqft H_2O<100 ppmv; slope=0.986, int=0.39
JPL H_2O (ppmv)
10-second data
lsqft:H_2O<1000 ppmv; slope=1.0372,int=0.14
HVD TW H_2O (ppmv)
10-second data
lsqft:H_2O<1000 ppmv; slope=1.026,int=0.43
HOx H_2O (ppmv)
HVD H_2O (ppmv)
10-second data
lsqft:H_2O<1000 ppmv; slope=1.009,int=0.94
ICOS H_2O (ppmv)
HVD H_2O (ppmv)
10^1
10^2
10^3

What do these and other intercomparison plots tell us about instrument performance?

$$\mathbf{H_2O}_{meas} = \mathbf{C}(Temperature, Pressure, H_2O_{amb}) \text{ X}$$

$$\textbf{Signal } (Temperature, Pressure, H_2O_{amb})$$

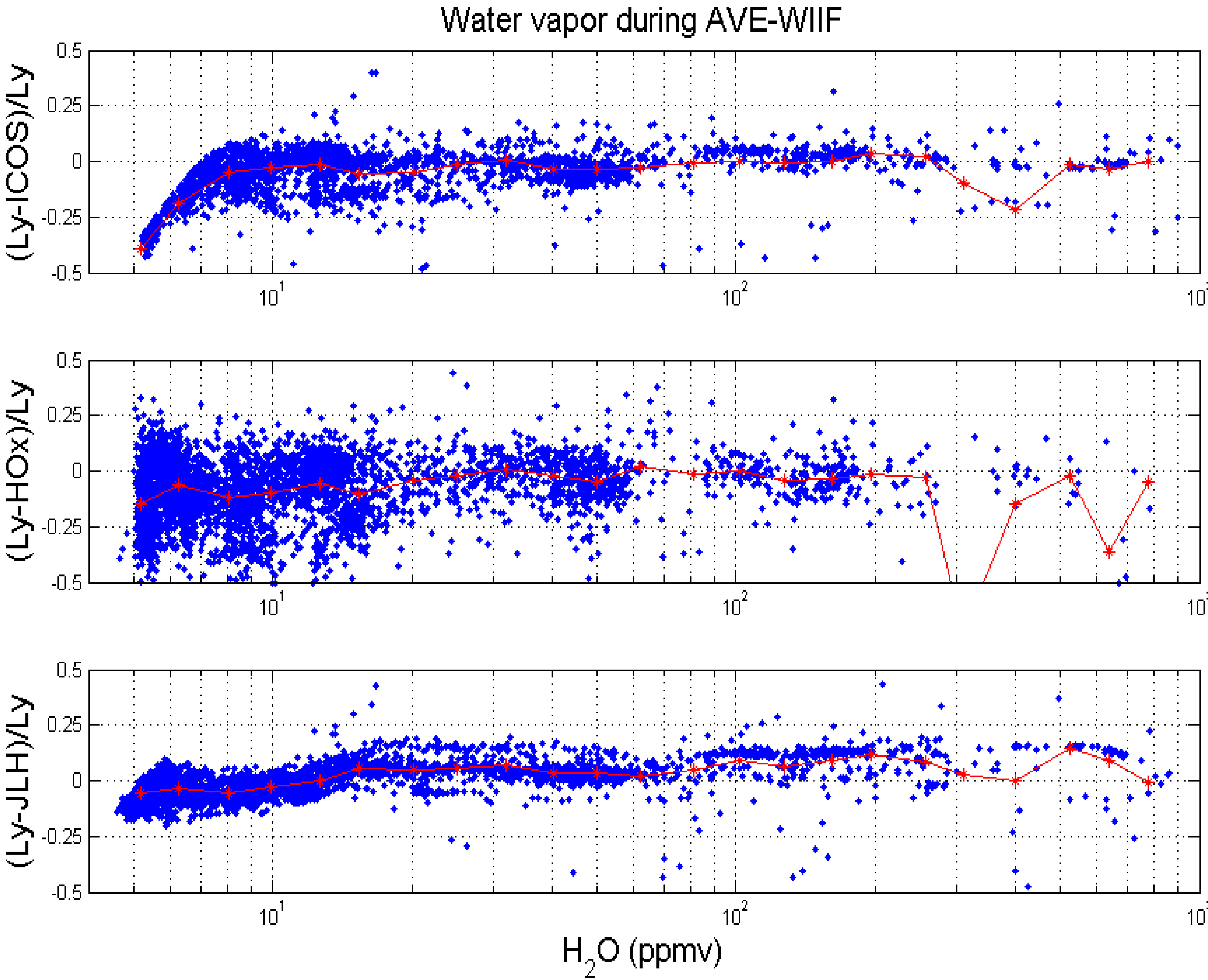
$$\mathbf{H_2O}_{meas} = \mathbf{C}(Temperature, Pressure, H_2O_{amb} \pm H_2O_{inst} \pm H_2O_{???}) \text{ X}$$

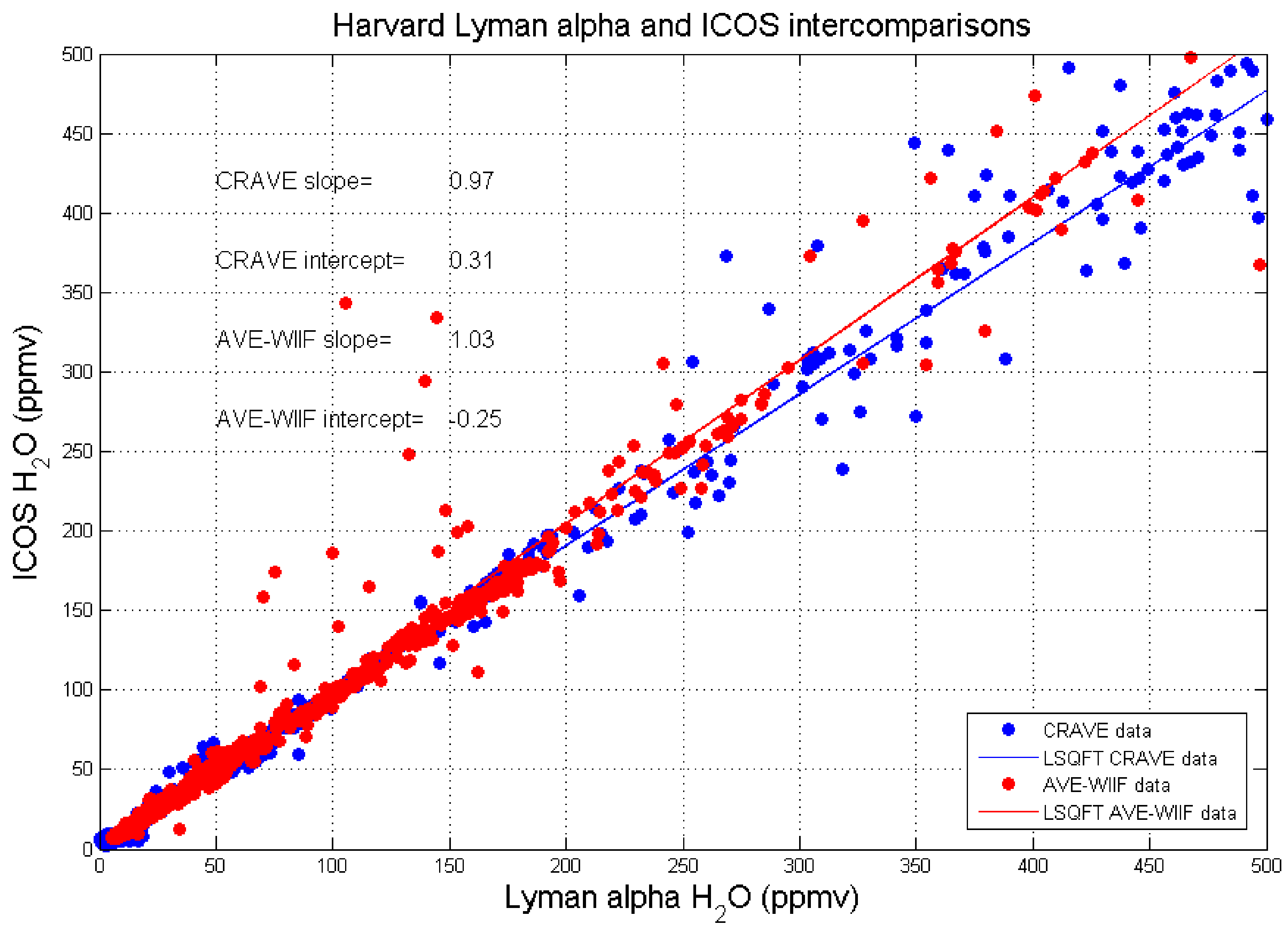
$$\textbf{Signal } (Temperature, Pressure, (H_2O_{amb} \pm H_2O_{inst} \pm H_2O_{???}))$$

C is the instrument calibration factor.

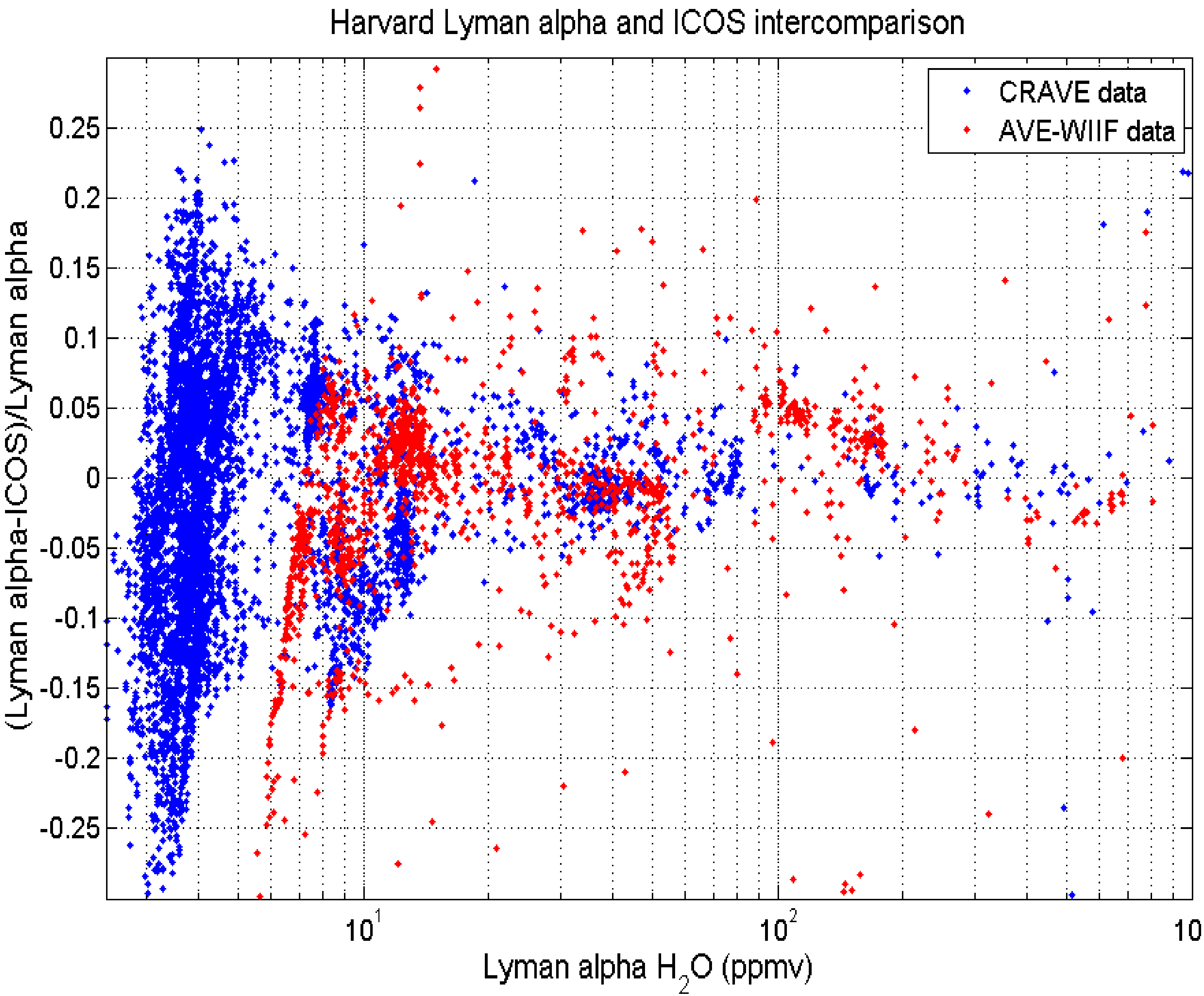
H_2O_{amb} is the true water vapor mixing ratio

H_2O_{inst} is the sum of contaminant water vapor from either the instrument or aircraft.

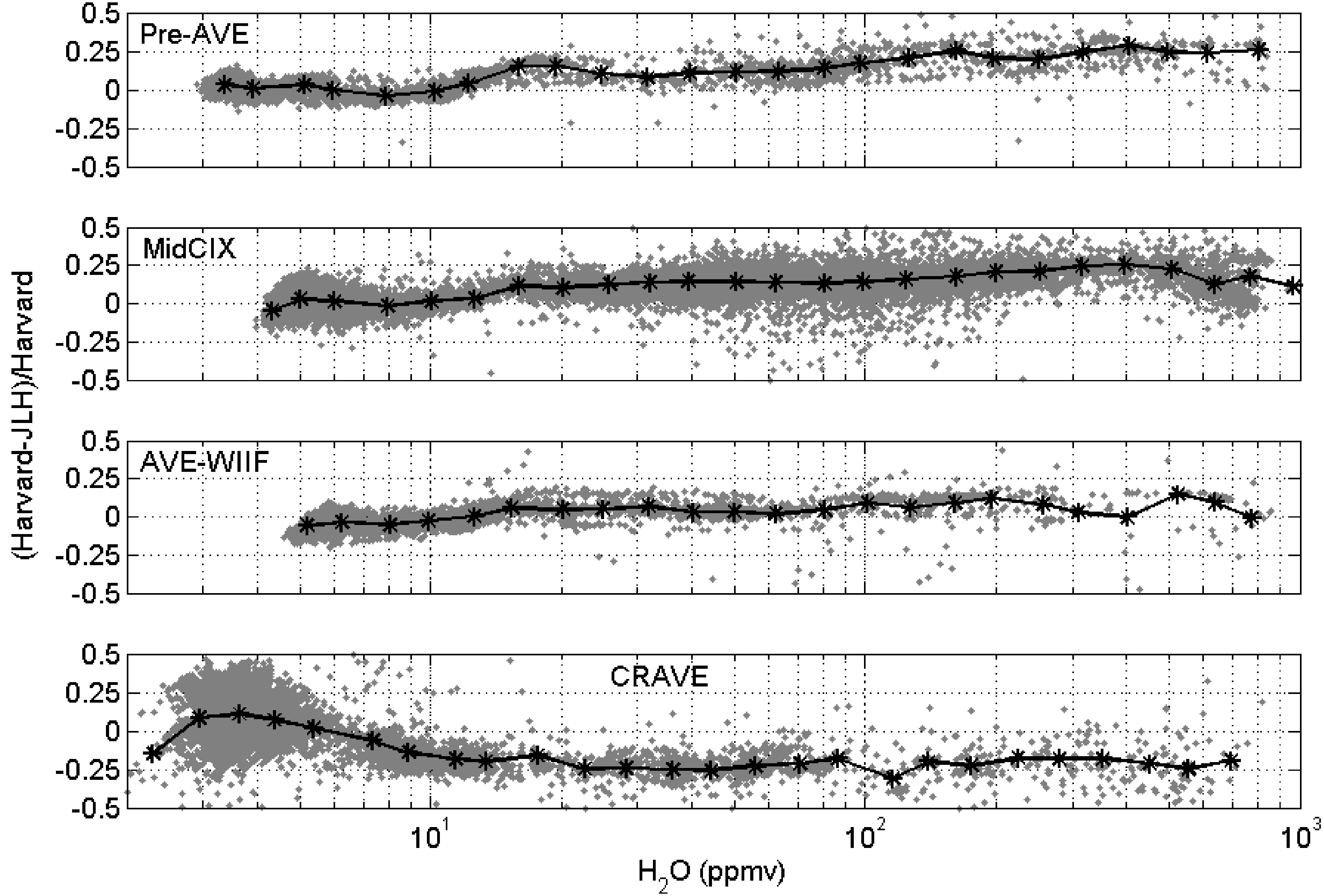

Water vapor during AVE-WIIF
(Ly-ICOS)/Ly
(Ly-HOx)/Ly
(Ly-JLH)/Ly
0.5
0.25
0
-0.25
-0.5
10^1
10^2
10^3
H2O (ppmv)



Harvard Lyman alpha and ICOS intercomparisons
CRAVE slope= 0.97
CRAVE intercept= 0.31
AVE-WIIF slope= 1.03
AVE-WIIF intercept= -0.25
CRAVE data
LSQFT CRAVE data
AVE-WIIF data
LSQFT AVE-WIIF data
ICOS H2O (ppmv)
Lyman alpha H2O (ppmv)
0
50
100
150
200
250
300
350
400
450
500



Harvard Lyman alpha and ICOS intercomparison
CRAVE data
AVE-WIIF data
(Lyman alpha-ICOS)/Lyman alpha
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
10^1
10^2
10^3
Lyman alpha H_2O (ppmv)



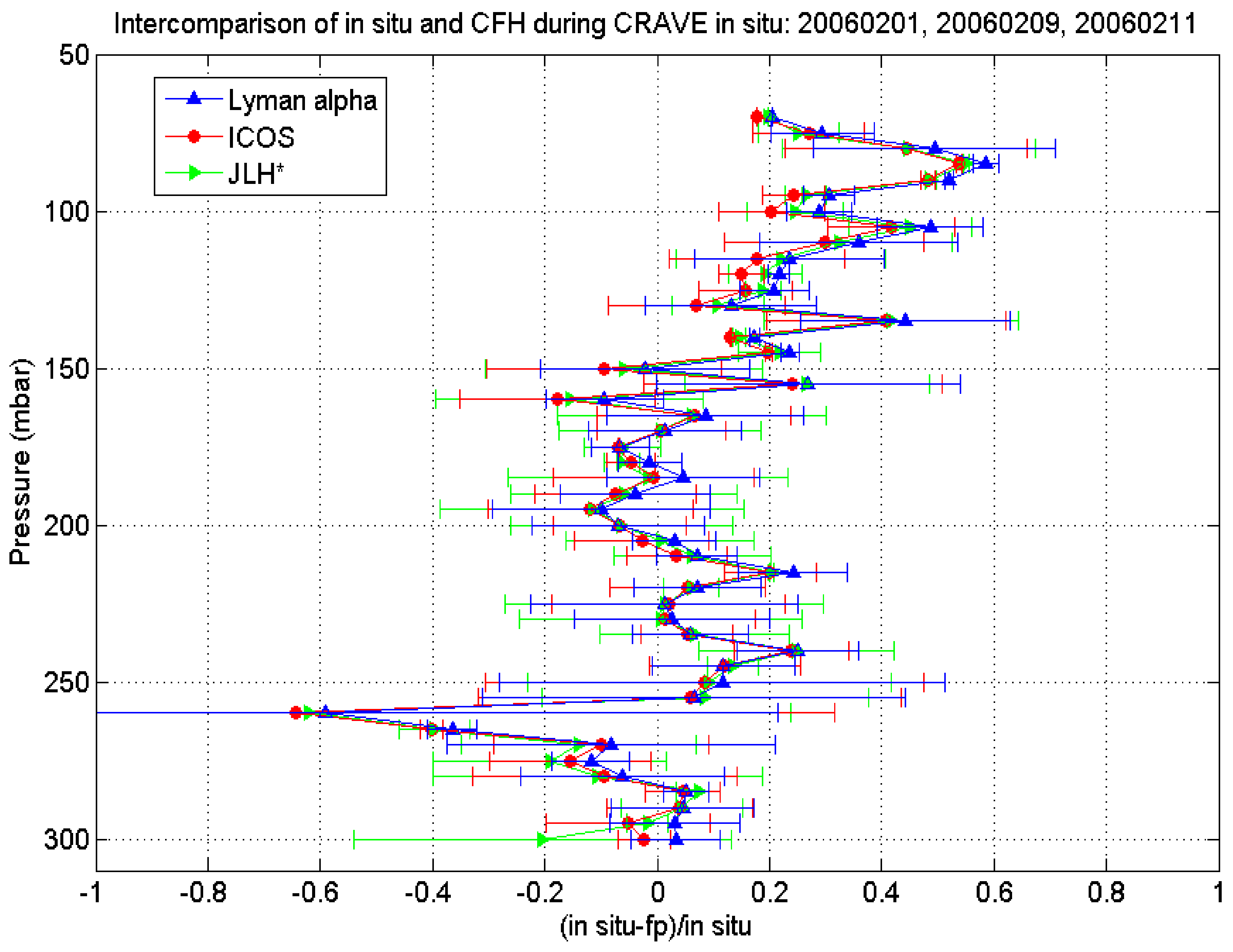
Pre-AVE
MidCIX
AVE-WIIF
CRAVE
(Harvard-JLH)/Harvard
H_2O (ppmv)
0.5
0.25
0
-0.25
-0.5
10^1
10^2
10^3

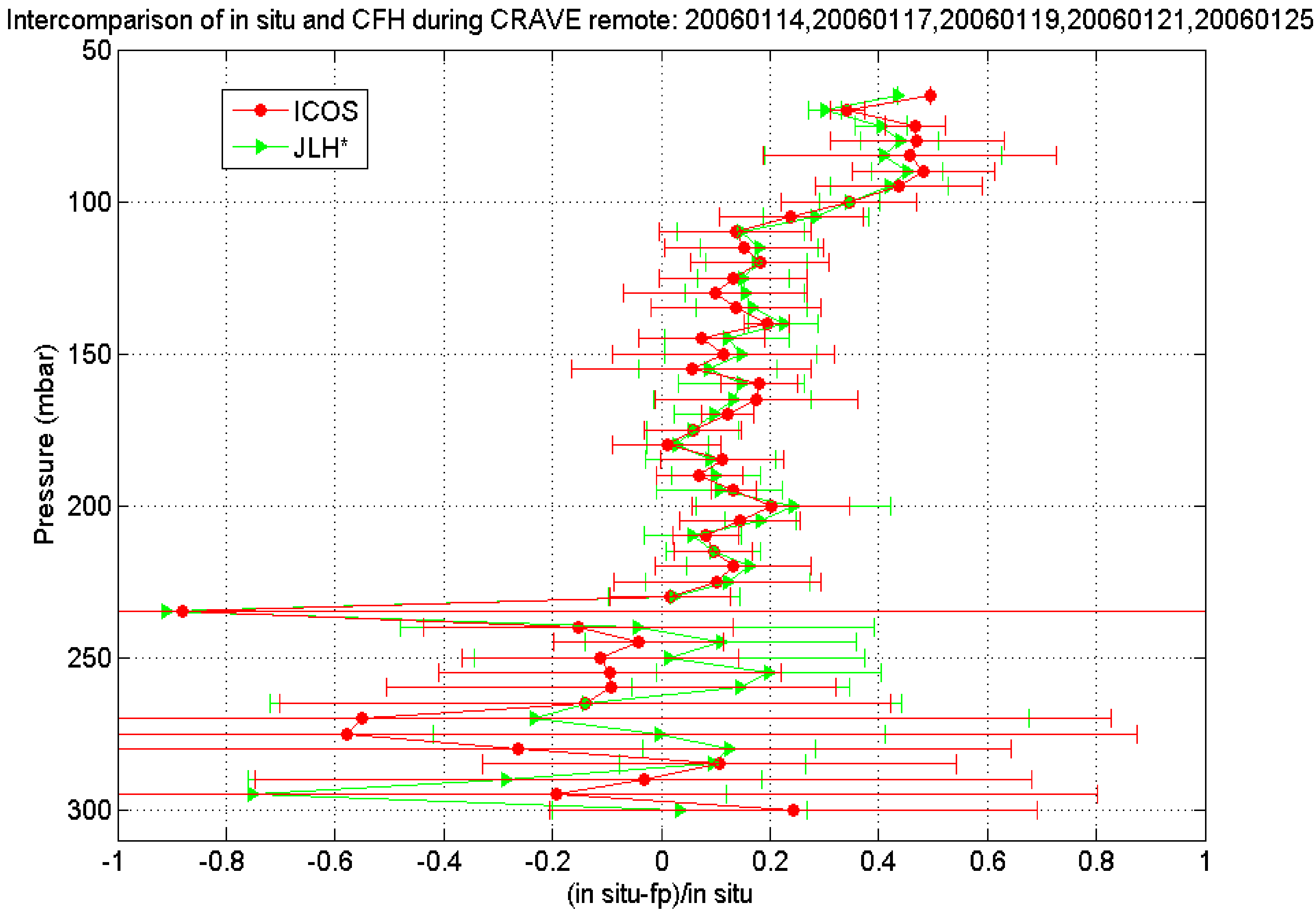
Goal: To compare WB57 water vapor with CFH during the entire CRAVE mission.

Approach: Adjust JLH to agree with Lyman α during in situ part of mission (January 30 – February 11), then use JLH* during the remote part of the mission (January 14 – January 27) as a surrogate for Lyman α,

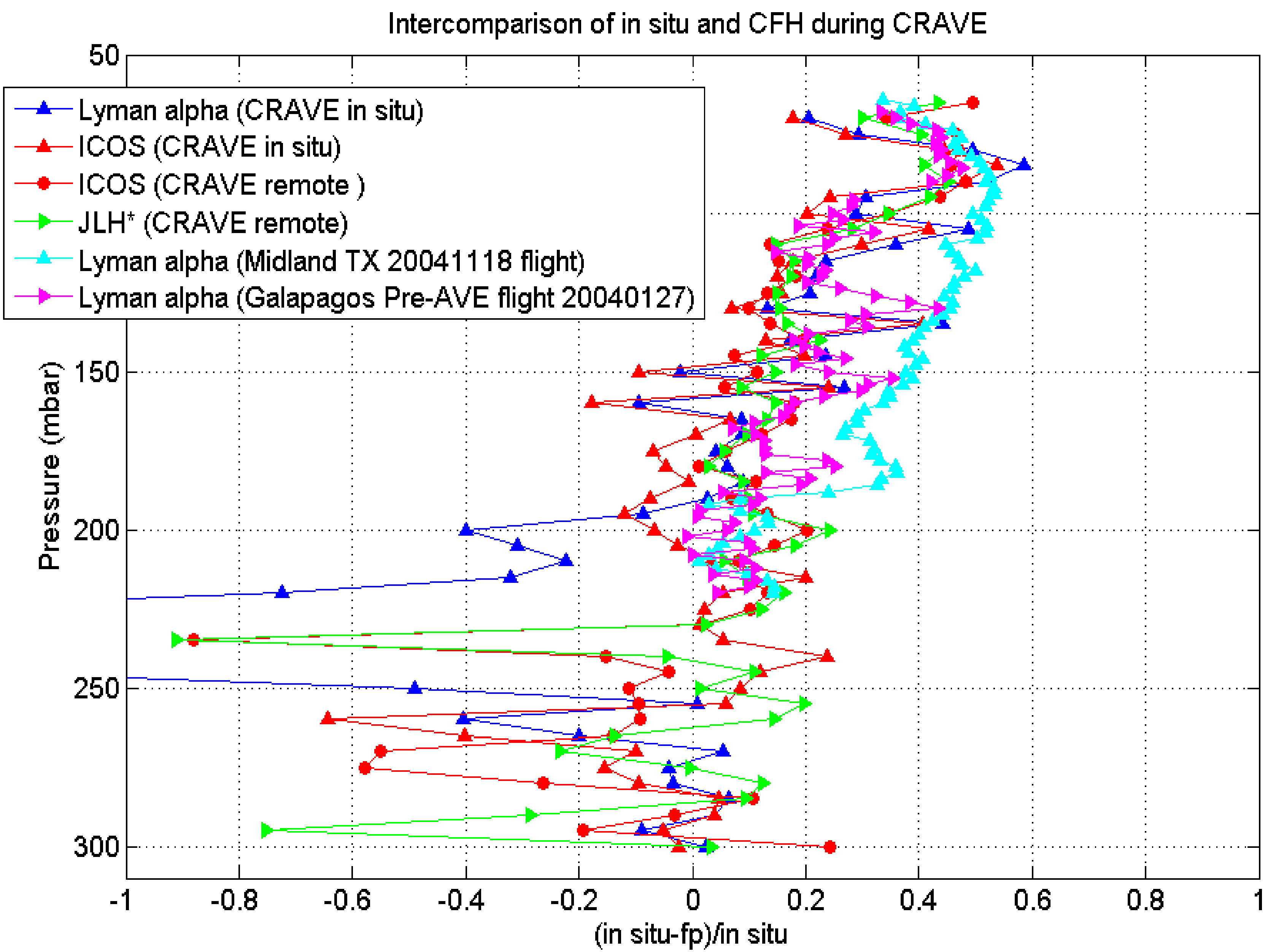
Where $JLH^* = 0.755 \cdot JLH + 1.1$

Comparison: Lyman α and ICOS with CFH during CRAVE in situ and JLH* and ICOS for CRAVE remote.

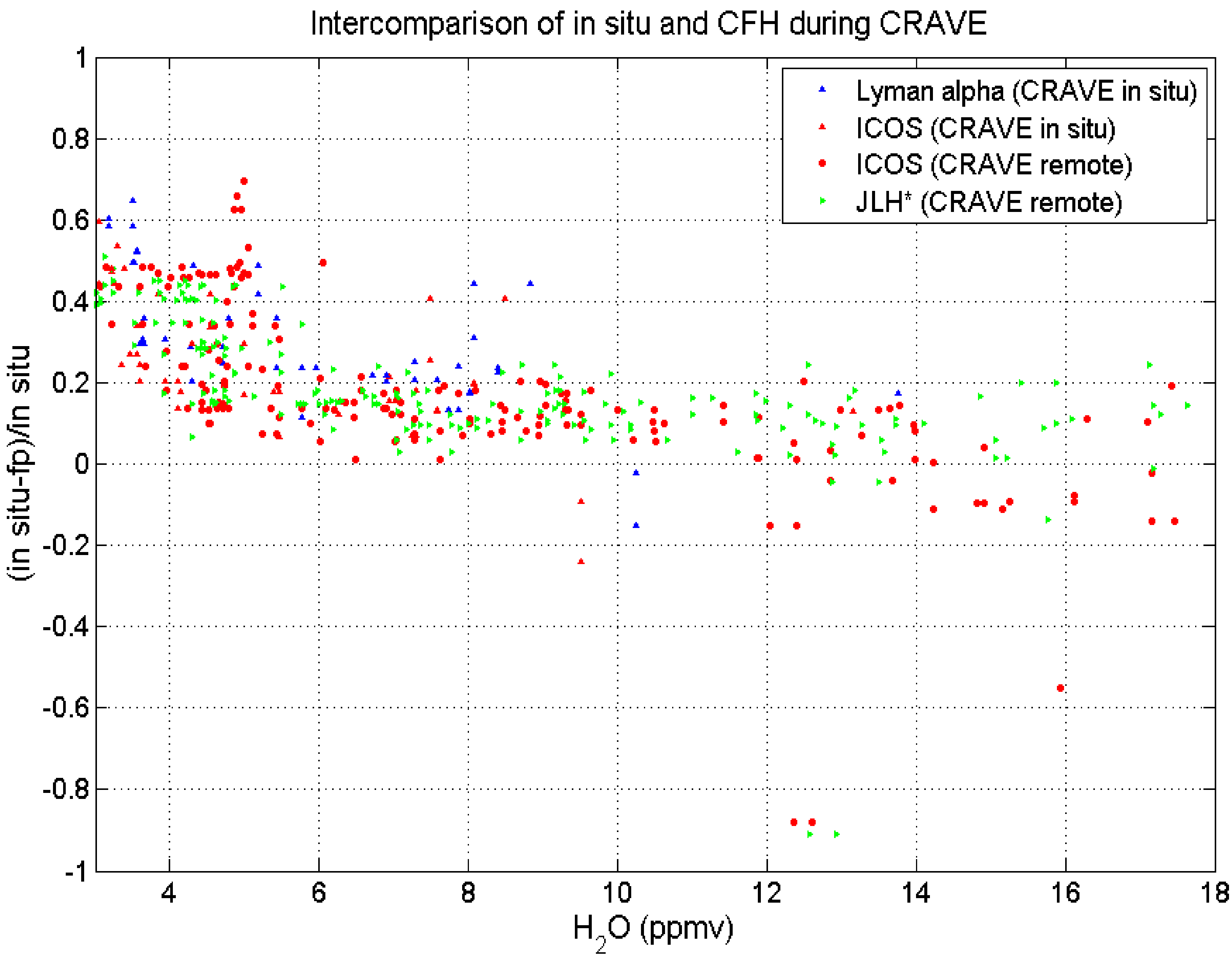

Intercomparison of in situ and CFH during CRAVE in situ: 20060201, 20060209, 20060211
Lyman alpha
ICOS
JLH*
Pressure (mbar)
50
100
150
200
250
300
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
(in situ-fp)/in situ



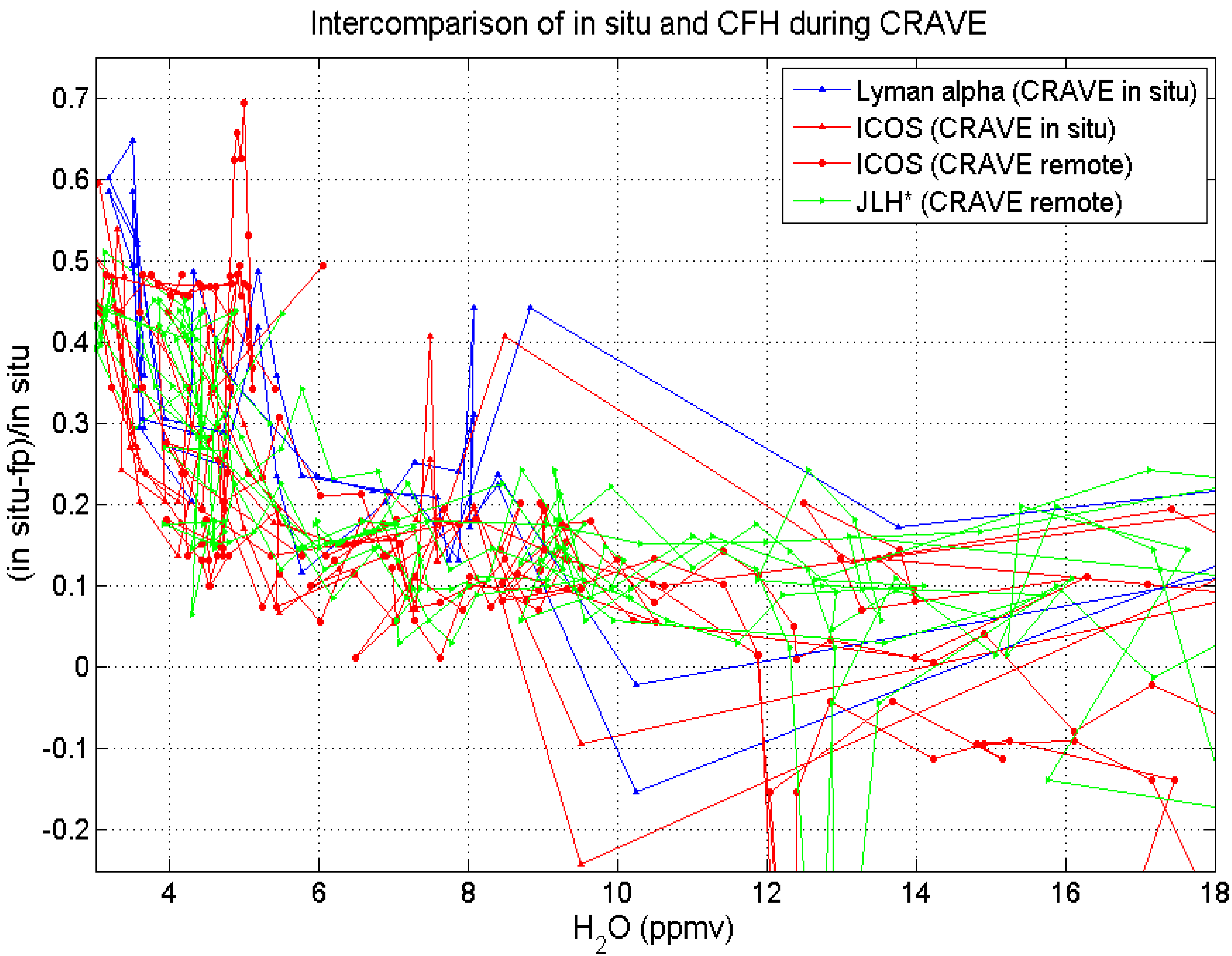
Intercomparison of in situ and CFH during CRAVE remote: 20060114,20060117,20060119,20060121,20060125
ICOS
JLH*
Pressure (mbar)
50
100
150
200
250
300
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
(in situ-fp)/in situ



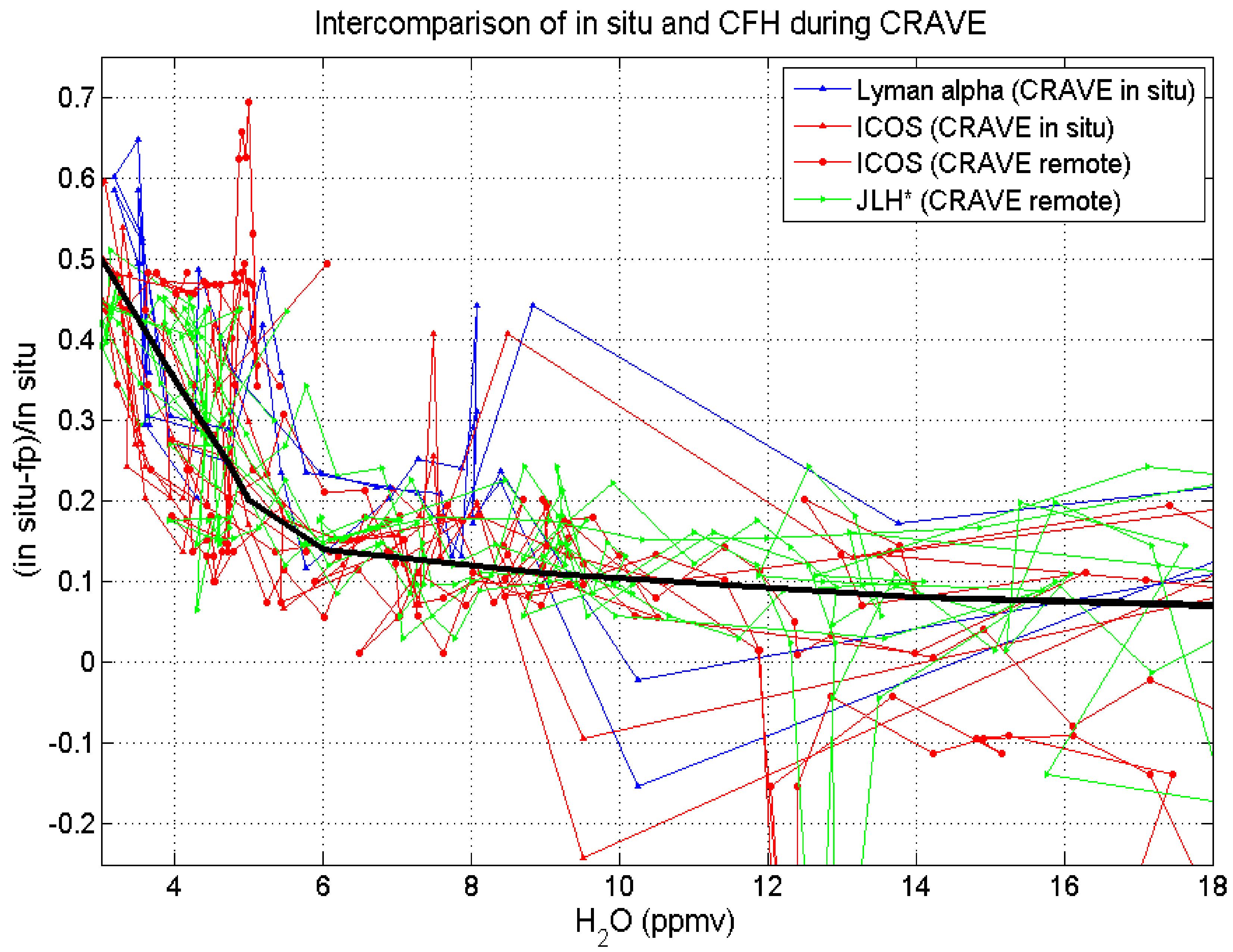
Intercomparison of in situ and CFH during CRAVE
Lyman alpha (CRAVE in situ)
ICOS (CRAVE in situ)
ICOS (CRAVE remote)
JLH* (CRAVE remote)
Lyman alpha (Midland TX 20041118 flight)
Lyman alpha (Galapagos Pre-AVE flight 20040127)
Pressure (mbar)
50
150
200
250
300
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
(in situ-fp)/in situ



Intercomparison of in situ and CFH during CRAVE
Lyman alpha (CRAVE in situ)
ICOS (CRAVE in situ)
ICOS (CRAVE remote)
JLH* (CRAVE remote)
(in situ-fp)/in situ
H2O (ppmv)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
4
6
8
10
12
14
16
18



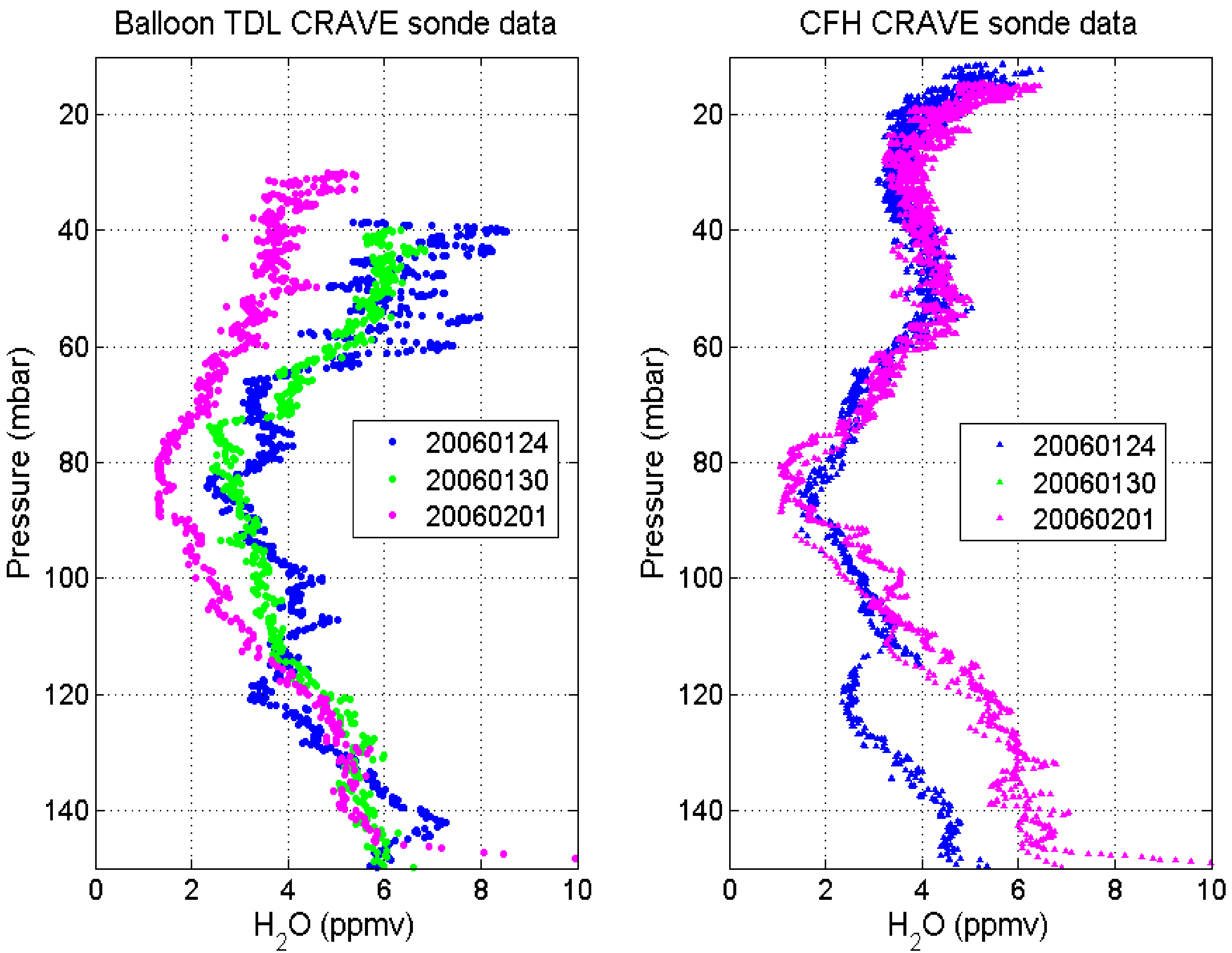
Intercomparison of in situ and CFH during CRAVE
Lyman alpha (CRAVE in situ)
ICOS (CRAVE in situ)
ICOS (CRAVE remote)
JLH* (CRAVE remote)
(in situ-fp)/in situ
H2O (ppmv)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
4
6
8
10
12
14
16
18



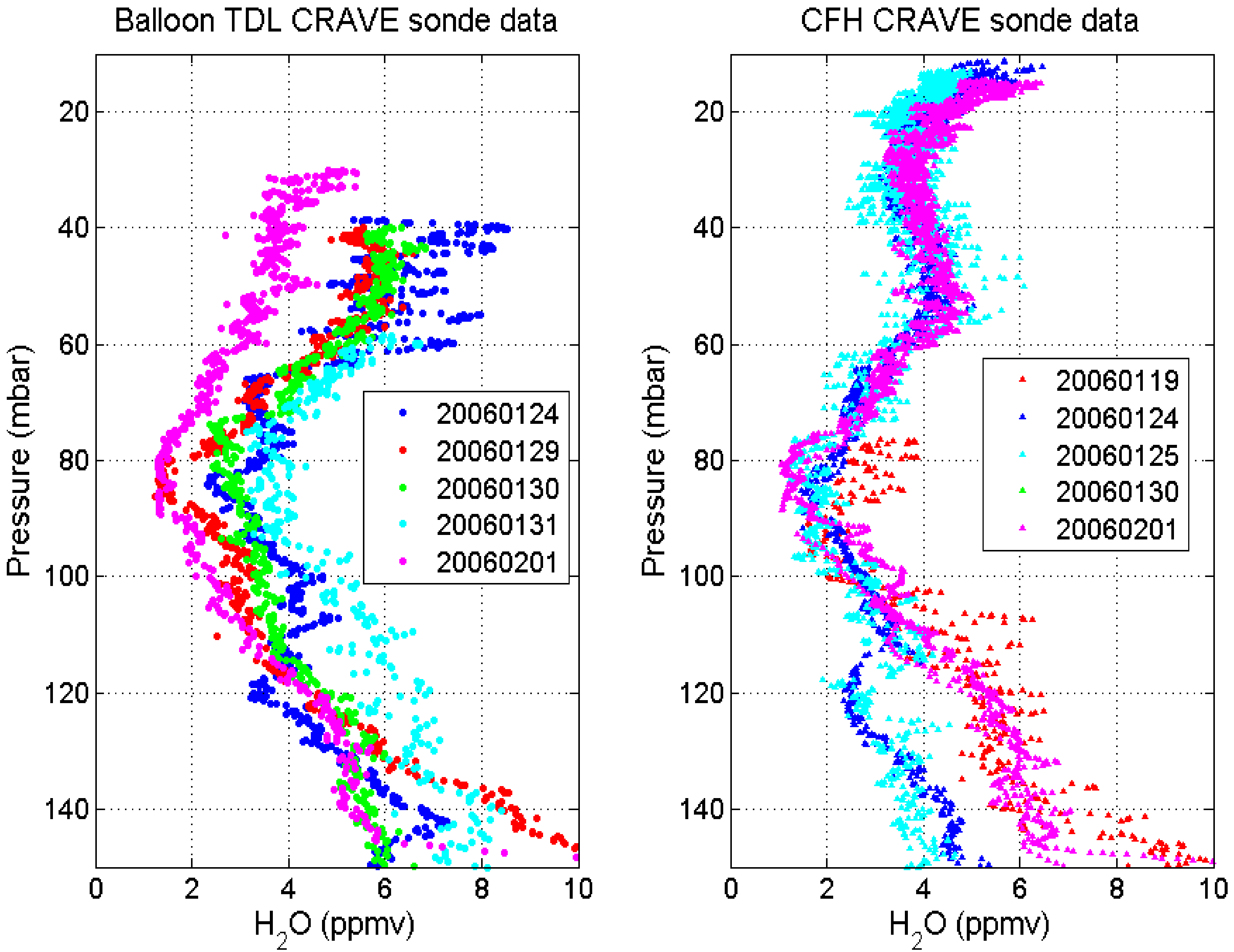
Intercomparison of in situ and CFH during CRAVE
Lyman alpha (CRAVE in situ)
ICOS (CRAVE in situ)
ICOS (CRAVE remote)
JLH* (CRAVE remote)
(in situ-fp)/in situ
H2O (ppmv)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
4
6
8
10
12
14
16
18

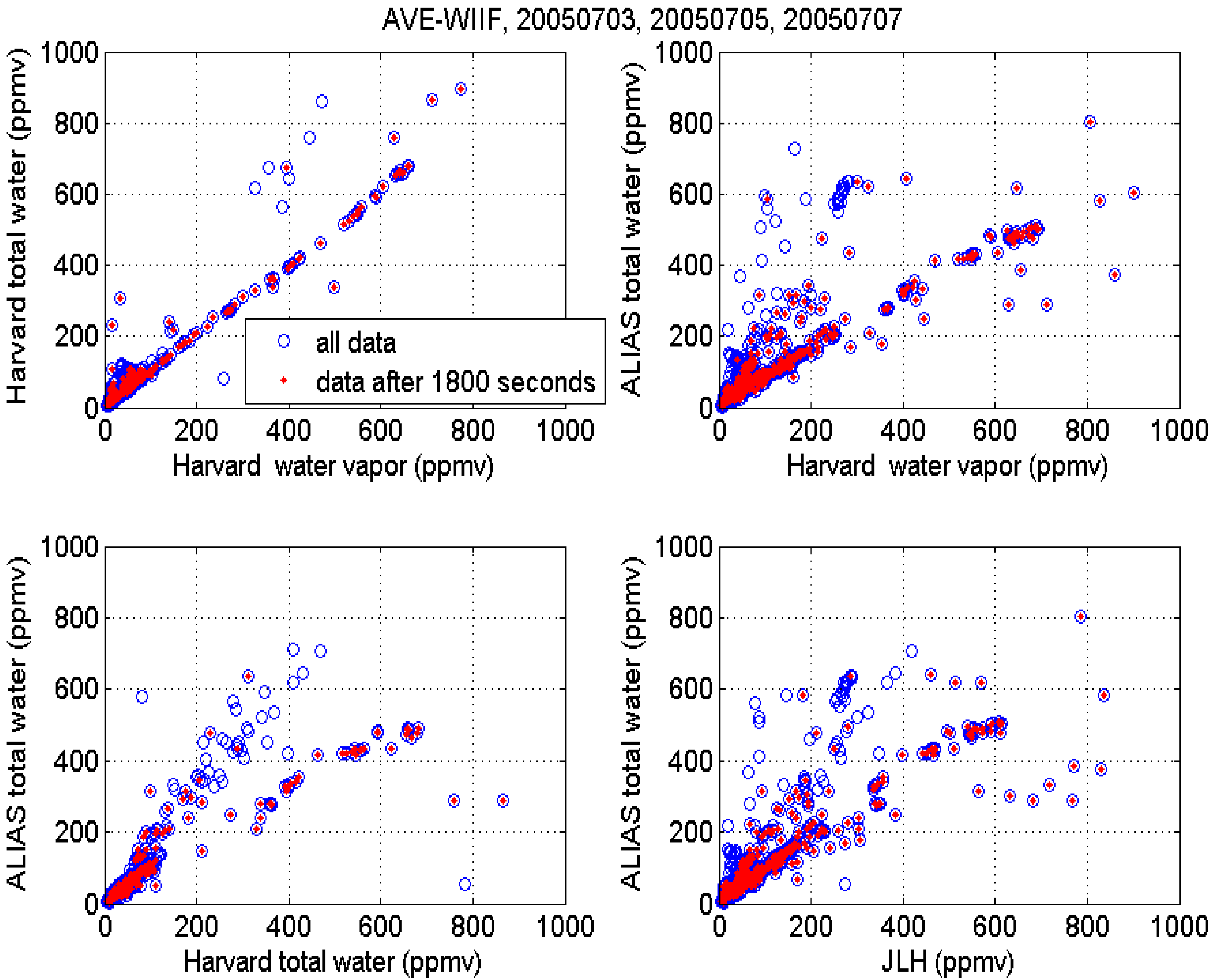
Conclusions

- As in AVE-WIIF, the overall agreement between Harvard water vapor instruments during CRAVE was very good.
- Comparisons between in situ water vapor on the WB57 and the CFH instrument illustrate systematic differences that increase significantly at low water vapor.
- Missions that provide the opportunity for careful water intercomparisons continue to be very useful and need to continue.
- Laboratory intercomparisons with low water vapor mixing ratios need to be carried out to help determine the source of this discrepancy.



Balloon TDL CRAVE sonde data
CFH CRAVE sonde data
Pressure (mbar)
H2O (ppmv)
20060124
20060130
20060201
20
40
60
80
100
120
140
0
2
4
6
8
10


Balloon TDL CRAVE sonde data
CFH CRAVE sonde data
Pressure (mbar)
20
40
60
80
100
120
140
0
2
4
6
8
10
H2O (ppmv)
20060124
20060129
20060130
20060131
20060201
20060119
20060125



AVE-WIIF, 20050703, 20050705, 20050707
Harvard total water (ppmv)
Harvard water vapor (ppmv)
all data
data after 1800 seconds
ALIAS total water (ppmv)
Harvard water vapor (ppmv)
ALIAS total water (ppmv)
Harvard total water (ppmv)
ALIAS total water (ppmv)
JLH (ppmv)
0
200
400
600
800
1000

The salient points of the operation, calibration, and in-flight validation of the Harvard water vapor are:

- Calibrations are carried out at a range of pressures and water vapor mixing ratios that are traceable to both the vapor pressure of water over liquid at room temperature and the absorption cross section of water vapor at Lyman-α (121.6 nm)

- In-flight measurements are carried out over a range of flow velocities (typically 20–80 m/s) to validate insensitivity to wall effects.

- ΔH_2O, measured by fluorescence using the laboratory calibration is cross-checked against ΔH_2O measured by dual path absorption. This cross-check validates the applicability of the laboratory calibration to in-flight conditions.

- During recent campaigns, agreement between the Harvard water vapor and total water instruments (in clear air) validates the insensitivity of the water vapor laboratory calibration to the in-flight temperature of the detection axis.